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Overview of the Geology and Mineral Resources of the Buckskin and Rawhide Mountains

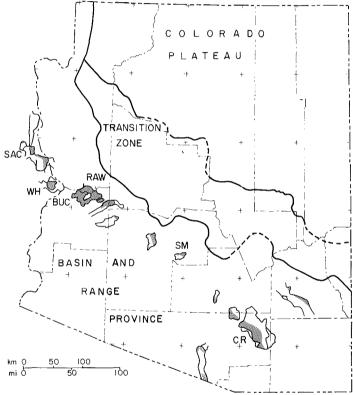
by Jon E. Spencer and Stephen J. Reynolds Arizona Geological Survey

The Arizona Geological Survey has made a major effort during the past 5 years to understand the geology and mineral resources of the Buckskin and Rawhide Mountains. The results of these studies and several studies by other geologists are presented in the Arizona Geological Survey Bulletin 198, from which the following text has been excerpted. This technical bulletin, which is now in press, represents a major addition to the geologic literature on the State and should be of interest to anyone concerned with the geology and mineral deposits of west-central Arizona.

Introduction

Crustal extension and compression, involving large horizontal movements of the Earth's crust, are major processes that have shaped the crustal architecture of planet Earth. Compression has long been recognized as the chief architect of most mountain belts and is now moderately well understood. In contrast, the contribution of extension to the structure of the crust is less well understood because many extensional structures were only recently recognized and because areas affected by crustal extension are typically buried by sediments.

Cenozoic extension in western North America has left a geologic record that, for areas of extensional tectonism, is unsurpassed in its visibility. Geologic features related to Cenozoic extension are especially amenable to study in the arid southwestern United States where bedrock exposure approaches 100 percent. Approximately 25 mountain ranges or groups of ranges in western North America are characterized by a distinctive association of geologic features that defied interpretation until the early 1980's. These ranges or groups of ranges are commonly referred to as metamorphic core complexes. Distinguishing features include a major low-angle normal fault (referred to as a detachment fault) that separates brittlely distended and generally highly faulted rocks above the fault from crystalline rocks below the fault that commonly have a gently to moderately dipping mylonitic foliation. Most geologists now interpret such faults and foliations as products of large-magnitude crustal extension. These distinctive features have been recently recognized in parts of Greece, China, and New Guinea, which indicates that Cordilleran metamorphic core complexes are not idiosyncrasies of western North America geology, but are general products of extensional tectonism. The Buckskin and Rawhide Mountains, which are part of the Harcuvar metamorphic core complex in west-central Arizona (Rehrig and Reynolds, 1980), contain one of North America's most



Lineated mylonitic rocks in metamorphic core complexes

Figure 1. Map of Arizona showing the three physiographic provinces in the State and the locations of lineated mylonitic rocks in metamorphic core complexes. BUC = Buckskin Mountains; CR = Santa Catalina Rincon Mountains; RAW = Rawhide Mountains; SAC = Sacramento Mountains; SM = South Mountain; WH = Whipple Mountains.

areally extensive exposures of a detachment fault and its mylonitic footwall.

Evidence of mineralization is abundant along the Buckskin-Rawhide detachment fault, including economic deposits of copper and gold. Detachment-fault-related mineralization is nowhere better displayed in North America than in and around the Buckskin and Rawhide Mountains. This type of mineralization was first recognized in the southwestern United States in the late 1970's (Reynolds, 1980; Wilkins and Heidrick, 1982). The existence of geologically similar deposits has been proposed

(continued on page 6)

Figure 2 (right). Simplified geologic map of the Buckskin and Rawhide Mountains showing the location of important mines and geographic features. The Buckskin Mountains include all areas of bedrock south of the Bill Williams River and east of the Colorado River, unless otherwise labeled (modified from Spencer, 1989).

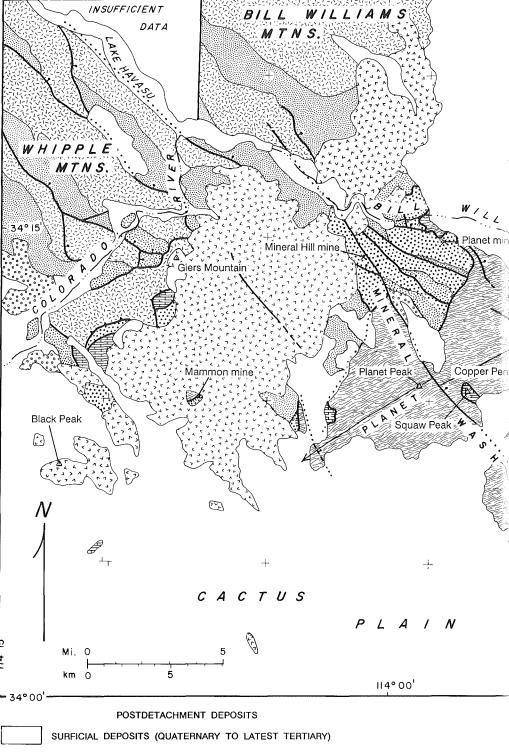
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for other areas in western North America, Spain, and New Guinea. The recently discovered Copperstone mine, Arizona's largest gold producer with annual production at approximately 60,000 ounces, is now known to be a detachment-faultrelated deposit (Spencer and others, Recent recognition of these 1988). deposits as a distinct deposit type and their association with metamorphic core complexes, which are themselves recently recognized and incompletely understood features, have sparked much scientific interest. Discovery of the Copperstone mine has also generated exploration interest in these deposits. The largest domestic deposits of manganese, a strategic and critical mineral, are present in the Artillery Mountains, which are adjacent to the Buckskin and Rawhide Mountains, and may have originated by processes associated with detachment faulting. Because of these geologic and mineral-resource attributes, the Buckskin and Rawhide Mountains have attracted considerable attention from geologists during the past 15 years, beginning with the pioneering Ph.D. study of the geology of the Rawhide Mountains by Terry Shackelford (Shackelford, 1976, 1989a,b; Davis, G.A., 1989).

Geology

The Buckskin and Rawhide Mountains are within the Basin and Range physiographic province of southwestern North America. This province, which includes southern and western Arizona, is characterized by numerous mountain ranges and intervening Cenozoic basins. The physiography of the Basin and Range Province is largely the product of middle and late Cenozoic low- and high-angle normal faulting, volcanism, and erosion. The significance and relative age of each of these processes vary greatly from range to range. Miocene low-angle normal faulting was the dominant process that determined the physiography of the Buckskin and Rawhide Mountains. Younger basaltic volcanism, erosion, and minor, postdetachment high-angle faulting were also important.

Cordilleran metamorphic core complexes are typically characterized by normal-faulted and extended hangingwall rocks that overlie well-lineated,



BASALT AND LOCAL INTERMEDIATE TO SILICIC VOLCANIC ROCKS AND SEDIMENTARY ROCKS, FLAT-LYING TO GENTLY TILTED (MIDDLE TO LATE MIOCENE)

SEDIMENTARY ROCKS (MIDDLE TO LATE MIOCENE)

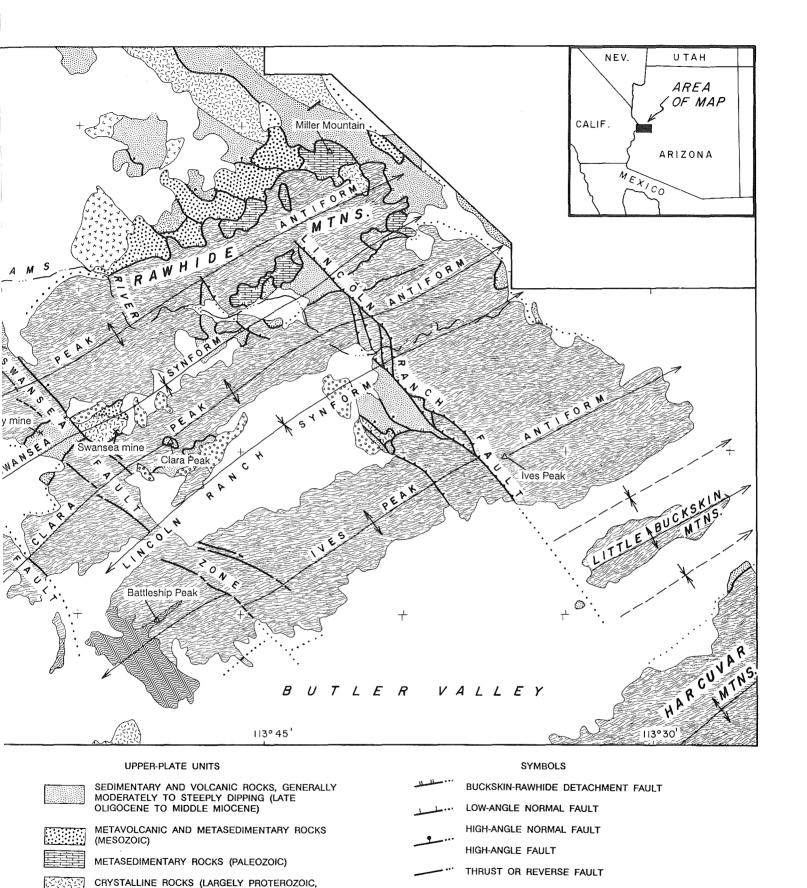
LOWER-PLATE UNITS

MYLONITIC CRYSTALLINE ROCKS (TERTIARY TO PROTEROZOIC)

MYLONITIC METASEDIMENTARY ROCKS (MESOZOIC TO PALEOZOIC)

variably mylonitic footwall rocks along large-displacement, Tertiary low-angle normal faults (detachment faults). The

Harcuvar metamorphic core complex, which includes the Buckskin and Rawhide Mountains, is one of the approx-



imately 10 such complexes that are discontinuously exposed in a belt extending diagonally across Arizona into southeastern California (Figure 1). Metamorphic

LOCALLY TERTIARY AND MESOZOIC)

core complexes have been intensively studied during the past 15 years. These once enigmatic associations of rocks and structures are now generally recognized as products of large-magnitude displacement on moderately to gently dipping normal faults and their down-dip continuations as ductile shear zones.

ALL FAULTS DASHED WHERE APPROXIMATELY

LOCATED OR INFERRED, DOTTED WHERE CONCEALED.

The subhorizontal Buckskin-Rawhide detachment fault is exposed discontinuously throughout the Buckskin and Rawhide Mountains (Figure 2). Hangingwall rocks, collectively referred to as the upper plate, consist of a variety of complexly normal-faulted and tilted rocks that include syntectonic, mid-Tertiary sedimentary and volcanic rocks and variably deformed and metamorphosed, Mesozoic and Paleozoic sedimentary and volcanic rocks (Figure 3). The footwall block, commonly referred to as the lower plate (platelike form is not implied), is composed of variably mylon-itic crystalline and metasedimentary rocks and is thought to be structurally continuous with similar lower-plate rocks in the nearby Harcuvar and Whipple Mountains. The mid-Tertiary age of some of the mylonitized rocks in the Whipple, Buckskin, and Rawhide Mountains has recently been established by U-Pb (zircon) geochronologic study (Wright and others, 1986; Bryant and Wooden, 1989). A northeastward direction of displacement of upper-plate rocks relative to the lower plate is inferred based on a number of criteria (e.g., Davis, G.A., and others, 1980; Reynolds and Spencer, 1985; Howard and John, 1987). The sense of displacement on the detachment fault is the same as that indicated for mylonitization by asymmetric petrofabrics in the mylonites

(Davis, G.A., and others, 1986; Davis, G.A., and Lister, 1988; Marshak and Vander Muelen, 1989; Spencer and Reynolds, 1989b).

The detachment fault forms a corrugated surface defined by east-northeast-trending antiforms and synforms (Figure 4). Lower-plate foliation and lithologic layering broadly conform to the form of the detachment fault, at least in areas where exposure through the lower plate is good, such as the east face of Planet Peak and the west face of Ives Peak (Figure 2). The origin of these corrugations is unknown, but they are suspected to be related to detachment faulting and mylonitization because the direction of displacement on the detachment fault and mylonitic lineation are approximately parallel to antiform and synform axes.

Except for the corrugations, all of the basic Tertiary structural features in the Buckskin and Rawhide Mountains, and in metamophic core complexes in general, are accounted for by the shearzone model. This model envisions that each metamorphic core complex originated by large displacement on a master low-angle normal fault that extended down dip into a zone of mylonitization (Figure 5). According to this model, rocks originally mylonitized at perhaps 8- to 15-kilometer depth rose isostatically and cooled as they were displaced

BASALT (8-15 Ma) BASIN-FILL DEPOSITS (FLAT-LYING) SEDIMENTARY BRECCIA MAFIC FLOWS (≈ 20 Ma) LACUSTRINE LIMESTONE BASE OF TERTIARY SECTION METAMORPHOSED PALEOZOIC AND MESOZOIC SEDIMENTARY AND VOLCANIC ROCKS THRUST FAULT REPLACEMENT CARBONATE DETACHMENT FAULT CHLORITIC BRECCIA CARBONATE AND CALC-SILICATE SLIVER VARIABLY MYLONITIC CRYSTALLINE ROCKS

Figure 3. Schematic structure-stratigraphy diagram for the Buckskin and Rawhide Mountains showing all important pre-Pliocene rock types and some of their contact relationships. Movement on rotational normal faults (not shown) caused tilting of upper-plate rocks.

from beneath a wedge of brittlely extending upper-plate rocks, and were overprinted successively by chloritic alteration and brecciation, microbrecciation, and fault-gouge formation along a narrow fault zone (Wernicke, 1981, 1985; Davis, G.H., 1983; Reynolds, 1985; Davis, G.A., and others, 1986). Arching and subareal exposure of the lower plate led to shedding of mylonitic debris into syntectonic sedimentary basins and to the distinctive physiography of many of the complexes (Rehrig and Reynolds, 1980; Howard and others, 1982; Spencer, 1984; Pain, 1985; Miller and John, 1988; Spencer and others, 1989a).

Upper-plate rocks in the Buckskin and Rawhide Mountains contain abundant evidence of compressional deformation and metamorphism of Mesozoic and Paleozoic sedimentary rocks. The stratigraphy of the pre-Tertiary rocks is recognizable in spite of variable but typically severe deformation and greenschist-grade metamorphism (Reynolds and others, 1987, 1989; Reynolds and Spencer, 1989; Spencer and others, 1989b). Deformation occurred in association with generally south-directed, late Mesozoic thrust faulting within the eastwest-trending Maria fold-and-thrust belt (Reynolds and others, 1986).

Detachment faulting and related deformation and sedimentation were followed by dominantly basaltic volcanism with local associated felsic volcanism (Suneson and Lucchitta, 1983). Trachyte flows and interbedded pyroclastic rocks in the western Buckskin Mountains are the same age as, and may have evolved from, magmas associated with adjacent postdetachment basalts (Grubensky, 1989).

Mineralization and Alteration

Mineral deposits are widely distributed in the Buckskin and Rawhide Mountains and, with a few notable exceptions, are along or within a few tens of meters of the detachment fault (Figure 6). Most of the deposits contain massive or fracture-filling specular hematite and younger fracture-filling chrysocolla. Early-formed copper and iron sulfides were probably common, but are largely obscured by later oxidation. Hydrothermal-carbonate replacements are also present along the fault and are commonly associated with copper-iron mineral deposits. These deposits have yielded approximately 52 million pounds of copper and 15,500 ounces of gold, with minor amounts of lead, zinc, and silver (Keith and others, 1983). All of these deposits formed at the same time that detachment faulting and related structural and sedimentary phenomena occurred. They are believed to have

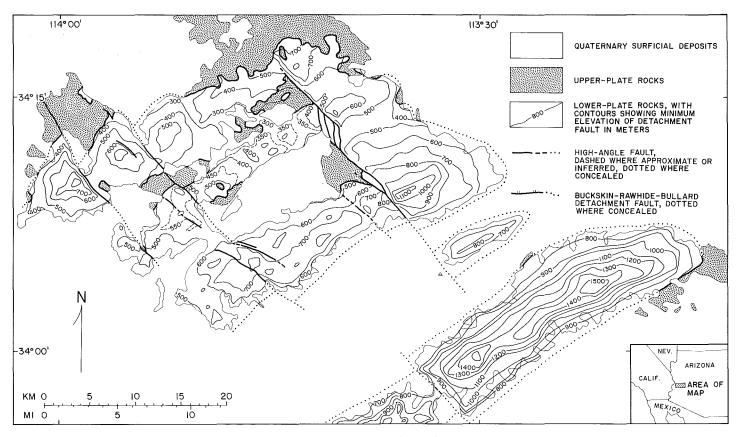
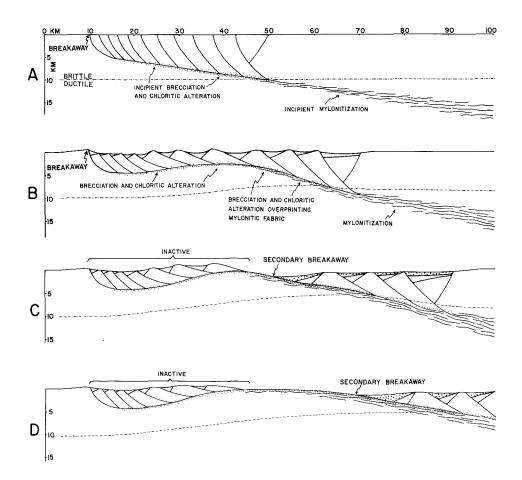


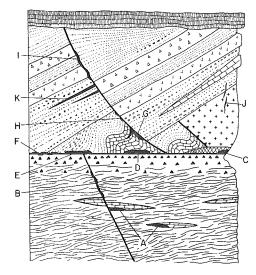
Figure 4 (above). Minimum-relief contour map of the Buckskin-Rawhide detachment fault.



formed from aqueous brines that leached metals from strata within extensional sedimentary basins (Wilkins and Heidrick, 1982; Spencer and Welty, 1986, 1989; Wilkins and others, 1986; Lehman and Spencer, 1989). The recent discovery of the Copperstone deposit in west-central Arizona, which is estimated to contain more than 500,000 ounces of gold and is related to the Moon Mountains detachment fault, has led to renewed interest in detachment-fault-related mineral deposits (Spencer and others, 1988).

Manganese deposits hosted in upperplate, Miocene sedimentary rocks in the Buckskin and Rawhide Mountains have yielded approximately 24 million pounds of manganese. Similar manganese deposits in the nearby Artillery Mountains are the largest of such deposits in the United States (Lasky and Webber, 1949). Some of the deposits in the Artillery Mountains are younger than previously suspected and may postdate detachment faulting and related mid-Tertiary tecto-These younger deposits formed from low-salinity fluids and thus were not derived directly from the saline aqueous fluids that caused detachmentfault-related mineralization (Spencer and others, 1989a).

Figure 5 (left). Cross-section evolution diagram of Miocene extension in the Buckskin and Rawhide Mountains.



In addition to manganese and detachment-fault-related mineralization, widespread potassium metasomatism of upper-plate rocks and chloritic alteration of brecciated rocks below the detachment fault attest to the pervasiveness of aqueous geochemical activity during detachment faulting (Figure 7). K metasomatism has been recognized elsewhere in association with detachment faults (Brooks, 1986, 1988) and is known to be than detachment-fault-related older mineralization in the eastern Harcuvar Mountains (Roddy and others, 1988). K metasomatism in the Buckskin Mountains has largely converted mafic volcanic flows, which may have originally been alkalic, to K-feldspar, calcite, and iron and manganese oxides (Kerrich and others, 1989). Plagioclase in K-metasomatized, upper-plate basalt flows in the Buckskin Mountains has been largely or entirely converted to K-feldspar; numerous K-Ar dates of feldspar concentrates from these rocks reveal a mid-Miocene age of K metasomatism (Spencer and others, 1989c). Chloritic alteration of lower-plate rocks, involving massive addition of iron, manganese, and magnesium and loss of silica, sodium, and potassium, occurred in a different fluid regime than that associated with later

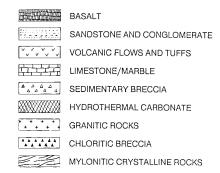


Figure 6. Sites of mineralization during detachment faulting.

calcite and iron-manganese-oxide vein emplacement (Reynolds and Lister, 1987; Halfkenny and others, 1989).

The abundant evidence for widespread mid-Tertiary mineralization and alteration suggests that complex chemical and physical processes operated on a scale at least as large as the metamorphic core complex itelf. Genetic relationships between copper + iron + gold mineralization and carbonate metasomatism along detachment faults, and K metasomatism and manganese mineralization in the upper plate, have not been established. All, however, were produced approximately synchronously in the same tectonic environment and are remarkably well developed in the Buckskin and Rawhide Mountains.

Conclusion

Better understanding of the genesis of metamorphic core complexes, their relationship to older tectonic features, and their associated mineral deposits and igneous rocks could elucidate the nature general processes that occur in extensional tectonic settings, including those related to the genesis of economic mineral deposits. The remarkably wellexposed and well-developed compressional and extensional structures and mineral deposits in the Buckskin and

Rawhide Mountains present an exceptional opportunity to improve basic geologic understanding.

Although Bulletin 198 represents a major step forward in deciphering the complex geologic evolution of a major Cordilleran metamorphic core complex, it is clear that many questions remain unanswered. One can only hope that future investigators find these problems interesting and tractable and that the momentum established since Terry Shackelford's pivitol dissertation will continue to advance the geologic understanding of this remarkable area.

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